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Wireless Sensor Network-Assisted Forest Fire Detection and Control Firefighting Robot

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Abstract

Forest fire is an uncontrolled fire that happens basically in timberland locales, indeed though it can moreover attack urban or country ranges. Among the main causes of quickly spreading fires, human variables, either deliberateness or coincidental, is the foremost typical ones. The number and impact of woodland fires are expected to create as a consequence of around the world warming. In arrange to fight against these fiascos, it is fundamental to receive a comprehensive, multifaceted approach that empowers continuous situational mindfulness and instant responsiveness. This paper portrays a hierarchical wireless sensor arrange pointed at early fire discovery in forest regions and informing fire work force approximately fire firsthand. Wireless Sensor Network (WSN) is coordinating with a semi-autonomous wirelessly controllable firefighting robot, these robots are actuated once a remote sensor organize recognizes fire and gives, to begin with, a line of defense against the spreading of wildfires and begins quenching fire until firefighters arrive.

Keywords: Fire fighting robot, Forest fire, Remote control, Semi-autonomy, Sensors, Wireless sensor network.

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Introduction

Annually, 200,000 rapidly spreading fires happen within the world. The yearly misfortune of the timberland makes up to 1.47 million hectares or 0.5% of it adds up to zone the yearly misfortune from fierce blazes can be surveyed as US$ 19.3 billion. Presentation to unforgiving conditions on the fire ground, such as, smoke inward breath, fire burns, overexertion/stress, or indeed being caught, is considered to be the most attributions to more than 60% of the firefighter passing and over 20% firefighter wounds. Timberland fires are a repetitive marvel, common or artificial, in numerous parts of the world. Defenseless regions are basically found in mild climates where pluviometry is tall sufficient to empower a critical level of vegetation, but summers are exceptionally hot and dry, making an unsafe fuel stack. Worldwide warming will contribute to expanding the number and significance of these calamities. Each season, not as it were our thousands of woodland hectares annihilated by wildland fires, but moreover resources, properties, and open assets and offices are devastated. Besides, firefighter and civilians are at hazard, with an awful toll on human lives.[1]

"Fires are clearly one of the major reactions to climate change, but fires are not as it were a reaction—they nourish back to warming, which nourishes more fires." As shown in Figure 1 when vegetation burns, the coming about the release of putting away carbon increments worldwide warming. The more fires, the more carbon dioxide discharged the more warming, and the more warming, the more fires. The exceptionally fine sediment, known as dark carbon, that is released into the environment by fires moreover pitch into warming.

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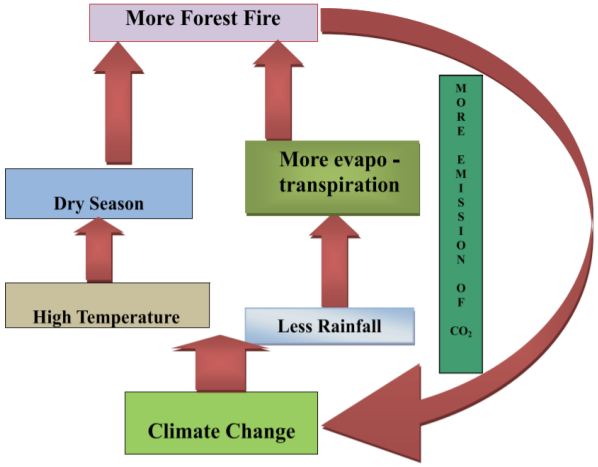

Figure 1: Effect of forest fire on climate change

Mechanical autonomy is playing critical parts of scholarly people and mechanically that help crisis reactions in unforgiving and perilous firefighting situations while avoiding operational staff from entering blocked off or risky locales. This paper creates to construct a remote sensor organize through disseminated remote sensors arbitrarily spread within the woodland and to make a self-organized and robust network between the sensors to cover expansive regions within the woodlands which will be inclined to/or in danger of fire harm at any time. Remote sensor arrange (WSN) comprises of spatially conveyed independent sensors to agreeably screen physical or natural conditions, such as, temperature, sound vibration, weight, movement, or toxins. In expansion to one or more sensors, each hub in a sensor arrange is regularly prepared with a radio handset or other remote communications gadget, a little microcontroller, a vitality source, and as a rule a cell or a battery.[2-5]

This paper too develops a state-of-art in WSN helped semi-autonomous firefighting robot to distinguish fireplaces and right away begin quenching fire until the fire warriors arrive. This robot moreover has charging capabilities utilizing sun powered boards and refilling of the water tank. This robot makes it conceivable to quench fire without spreading within the shortest time. This will diminish the hazard of harm and the number of casualties for firefighters, as well as, for the conceivable casualties. The robot can moreover diminish the money related misfortunes which increment impressively as fire length increments. This paper gives intrigue viewpoints to encourage smart firefighting. Robot too encompasses a durable rocker-bogie chassis. The rocker-bogie suspension framework latently keeps all six wheels on the robot in contact with the ground indeed on uneven surfaces. This makes for great traction and maneuverability.[6-8]

Overview

Impact

Fierce blazes are an imperative marvel on a worldwide scale, as they are capable of huge sums of financial and natural harm. These impacts are being exacerbated by the impact of climate alter. Rapidly spreading fire administrations are changing, rapidly spreading fire seasons are getting to be longer,[1] rapidly spreading fire normal sizes are expanding in numerous zones of the world, and fierce blazes are happening in regions, in which they did not happen in the past.[9,10] Climate alter is driving a few woodlands into a focused state, lessening the vegetation water substance, and driving to exceptionally prone-fire scenes, where high-severity rapidly spreading fires might happen. The number of yearly rapidly spreading fires are variable but has diminished marginally over the last 30 years, long time which the number of sections of land burned every year, whereas moreover variable, by and large, has increased.[11-13]

The Woodland Study of India information on timberland fire trait around 50 forest fire and its impact on 72% of the timberland zones as fire inclined. This does not signify that fires affect the country's 50 percent region yearly. Exceptionally, very heavy fire, heavy fire, frequent woodland fire, and incidental fire harm is taken note as shown in the Figure 2 as it were over 0.84, 0.14, 5.16, and 43.06% of the forest areas, separately. As it were 6.17% of the Indian forests are subjected to extreme fire harm yearly. In outright terms, out of around 63 million hectares of woodlands, and zone of around 3.73 million hectares can be assumed to be influenced by fires yearly.

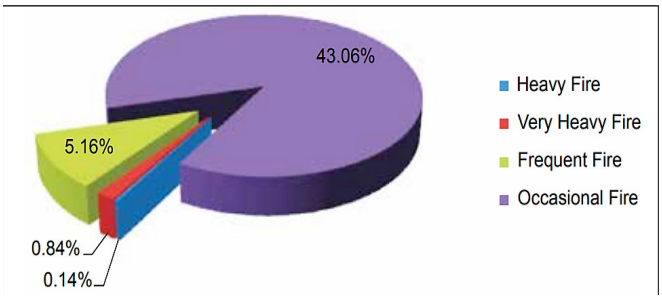

Figure 2: Annually forest area prone to fire in India

Current Firefighting Scenario

There are several government organizations that work on a hierarchical basis for maintenance, monitoring, and extinguishing of fire,[14] provides an overview about such organizations as shown in Figure 3. The Incident Responsive System (IRS) organization capacities through incident

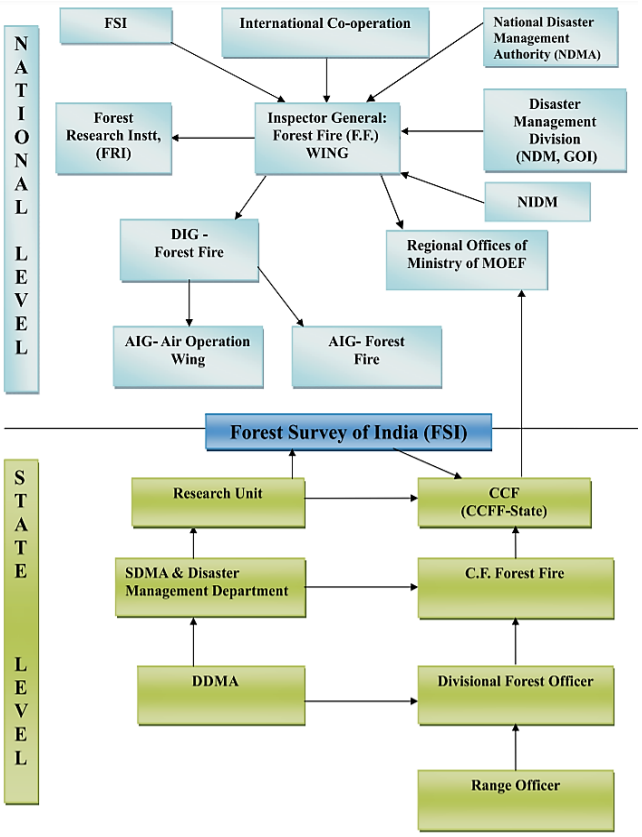

Figure 3: Proposed institutional framework for forest fire management

response teams (IRTs) for disaster administration. In Indian regulatory structure and Disaster Management Act, 2005, the responsible officers (ROs) have been assigned at state and local levels, as in general in charge of the incident commander (IC) who oversees the occurrence through IRTs, which are pre-assigned at all levels, i.e., state, area, subdivision, tehsil, and piece. The role of RO is to enact IRTs on receipt of any early caution of the disasters. In case a calamity happens without any caution, the neighborhood IRT will react and contact RO for advance bolster, in case required. The function of nodal officer (NO) is to preserve legitimate coordination between the district, state, and national levels in enacting discuss bolster for reaction.[15,16]

The Ministry of Environment and Forests (MoEF) has six zonal offices within the nation acting as planning workplaces with the state forest offices. These workplaces may be utilized to direct woodland fire management exercises and for this partitioned wing may be established, exclusively to see after the woodland fire. At the state level, the woodland fire administration operations are looked after by customary timberland staff.

Firefighting Robots

The utilize of mechanized frameworks in firefighting is being dynamically inspected due to firefighters routinely being uncovered to hazardous conditions to save lives. A mechanized system may well be a mechanical contraption that performs an errand utilizing sensors to see its environment, computer programs to control the robot based on its environment, and a human chairman to assist with robot operation. In 2011, 70,090 firefighters inside the U.S. alone were hurt inside the line of commitment with 61 passing. There is a combination of mechanical systems being made to support firefighters due to the wide expanse of fire occasions checking fires counting structures, vehicles, aircraft, ships, and wildlands.

There is an assortment of robotic systems as Table 1 shows being created to bolster firefighters due to the wide extend of fire occasions counting fires including structures, vehicles, airplanes, ships, and wildlands. In expansion to the wide extend of fire scenarios, the usefulness included within the robotic framework may get to shift to back firefighters in assignments, such as, measuring up the fire, recognizing caught individuals, finding the fire, observing conditions, controlling fire spread, and concealment.

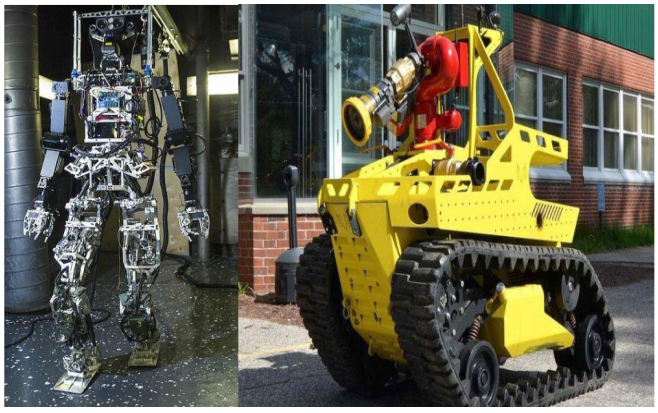

Figure 4: SAFFiR and Thermite firefighting robots

Firefighting robots, as shown in Figure 4 like SAFFiR, Thermite, etc., are good in the design but they all are manual controlled and lack in rough terrain mobility. They are not suitable for forest fire situations. Recently in the Notre Dame blaze, Paris firefighters used firefighting robots to extinguish the blaze.

Wireless Sensor Networks

The Fire Data and Protect Hardware venture at UC Berkeley has created a demonstrate inaccessible sensor organize (WSN) and event command (IC) interface for urban and mechanical firefighting and emergency response. A settled WSN sending inside the building acts as a spine of communication between a versatile workforce and event command. The Telos Sky mote 802.15.4 organize with the TinyOS working system is utilized for a grouping of recognizing and communication errands. These join localization, common checking, and dreary emergency communications.

Other Recommendations

One thing can be clearly noticed no firefighting robot is autonomous and placed inside the forest for easy and quick deployment. This paper develops a firefighting robot capable of instant deployment and is also assisted by the wireless sensor network. Implementing this system can help in the reduction of burnt areas and cost reduction involved in suppression cost. The passage time of firefighters and getting away the time of individuals are generally depending on the unobstructedness of firefighting and protected ways. As of now, robots do not sufficiently improve human certainty. The vital capabilities of robots are to recognize and interpret with their surroundings, and heavy physical tasks (HPT). In a perfect world, these capabilities ought to be accessible as a work of the energetic fire environment. To date, the functionalities of the firefighting robots are confined into data collection, fire location, remotely fire quenching, etc., and customarily no overwhelming physical assignments are assigned. In spite of significant headways within the advancement of sensor advances and mechanical technology for firefighting, there have been small interactions between robots and human

Table 1: Comparison of firefighting robots

Robot	*Type*	*Capabilities*
Anna Konda	Snake-like robot	Fire extinguishment/visual perception
LUF60	UGV	Fire extinguishment/smoke dispelling
FIREMOTE	UGV	Fire extinguishment/visual perception
SARRIR	Humanoid robot	Walking/manipulation fire suppressors
Brokk	Excavator-like robot	Demolition/stair climbing

recognitions of perceived visibility as recorded in field trials, and the comparable numerical framework reenactments of visibility in an energetic firefighting scene.

System Design

Block Diagram

The robot is built on a rocker bogie chassis having six wheels as shown in Figure 5. Arduino Mega 2560 is the microcontroller utilized to control all imperative frameworks on the robot. The double motor driver controls two motors separately. A remote module is utilized to control the robot wirelessly. The ultrasonic sensor senses and cautions the controller about the environment. The robot is powered by Lifepo4 batteries. When the fire is identified by the fire sensor the controller turns on the transfer which in turn begins the submersible pump and water fly gets made which extinguishes the fire.

The sensor node is powered by its own cell which powers it for more than three months. ATtiny85 is controlled by a little microcontroller as shown in Figure 6 which runs on a very little current draw which helps node to remain dynamic for months. A temperature sensor is utilized to sense the surrounding temperature and identify the spike which is right away identified by the microcontroller. The transceiver module is used to transmit the temperature sensor values to the sink node.

The sink hub is controlled by a NodeMCU microcontroller as shown in Figure 7 which encompasses a built-in Wi-Fi module. All sensor nodes transmit information to this node which sends this information into the cloud. The transceiver receives the temperature values and is sent to NodeMCU. Cloud or web is a platform where all temperature values are put away and processed. The client can wirelessly get to the values around any corner of the world and screen the temperature values and handle the same.

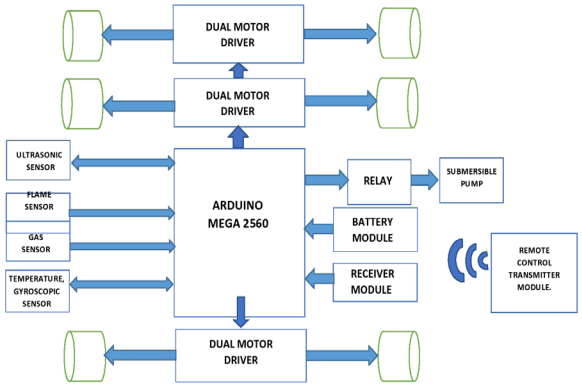

Figure 5: Block diagram of firefighting bot

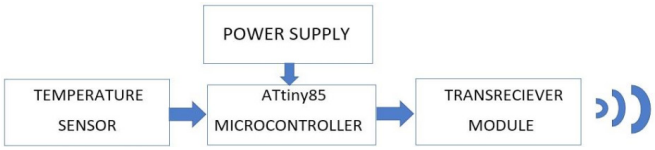

Figure 6: Block diagram of sensor node

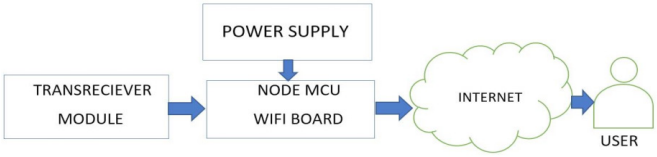

Figure 7: Block diagram of sink node

Architecture of WSN

Figure 8 shows architecture of wireless sensor networks, there are several sensor nodes that ceaselessly screen the surrounding timberland temperature and transmit the values to sink hub, i.e., Node MCU. Underneath each sensor node, there is a robot put prepared for activity. When a temperature spike is recognized the robot is called out and the fire is identified, and extinguishing begins. With that, the client is alarmed, and the fire division is intimated.

Flow Chart

Features

- First line of defense.
- Rocker bogie chassis for tackling uneven terrain.
- WSN continuously monitors forest temperature.
- Wireless monitoring.
- Wireless control of robot.
- Instant response for extinguishing of fire using robot.
- Wireless and instant intimation to fire department regarding forest fire.
- Scalable WSN.(Figure 9)

Algorithm

- Step 1: Initialize sensor nodes.
- Step 2: Read ambient temperature and detect fire.
- Step 3: Initialize sink nodes and collect sensor values from sensor nodes.
- Step 4: Upload sensor values on the Thingspeak platform.
- Step 5: When a fire is detected inform fire personnel and turns on the firefighting robot.
- Step 6: Robot senses ambient temperature and fire.
- Step 7: Detect distance from the fire.

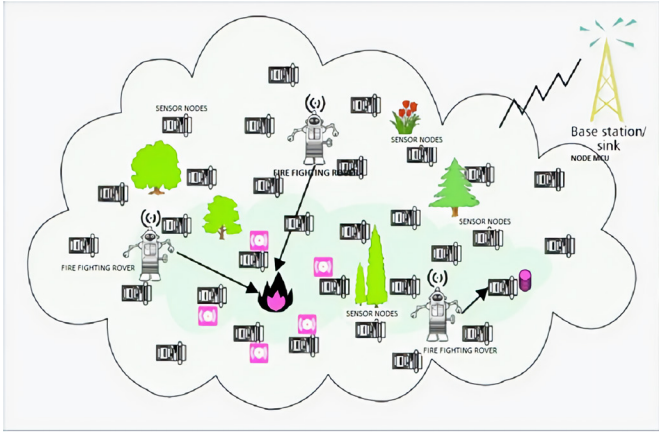

Figure 8: Wireless sensor network architecture

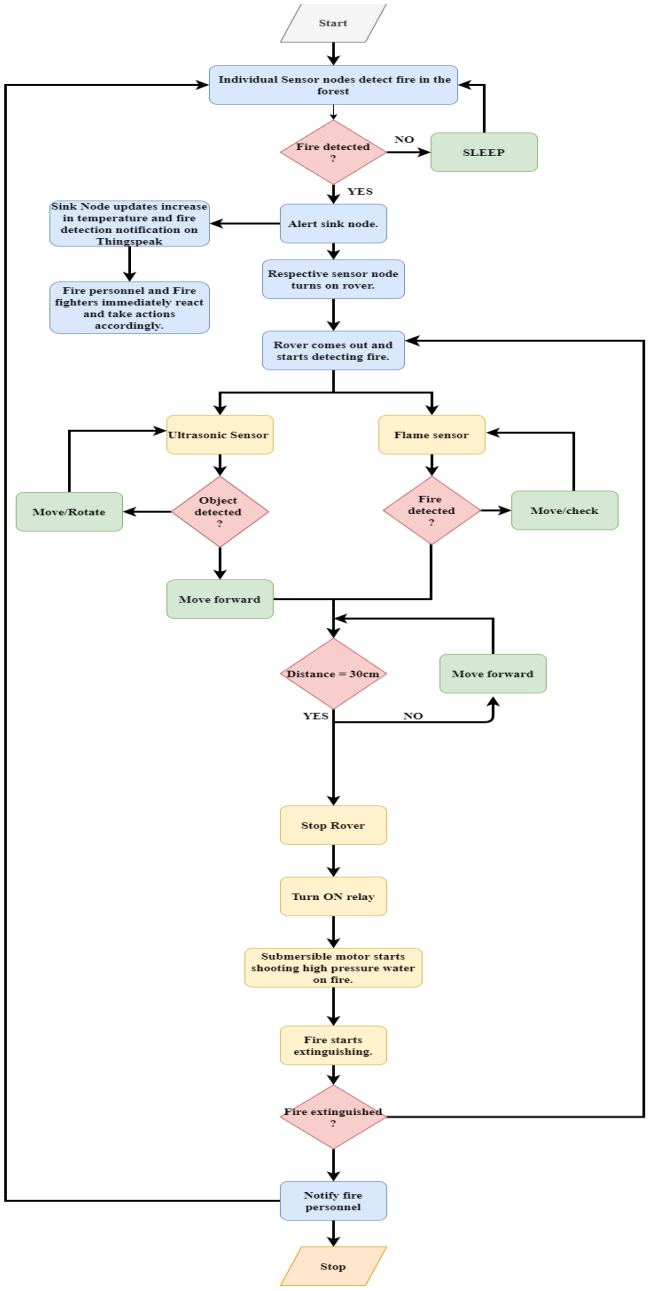

Figure 9: Code flow chart

- Step 8: When appropriate distance acquired turn on the submersible pump.
- Step 9: Once the fire is extinguished, go back to charging the battery and for filling the water tank.
- Step 10: Sensor nodes continuously monitor for fires.

Hardware Implementation

Hardware

The brain of the firefighting robot is Arduino Mega 2560. It has a total of 54 GPIOs which is very much needed for the large number of components which are to be interfaced. A dual motor driver drives to planetary geared DC motor. The

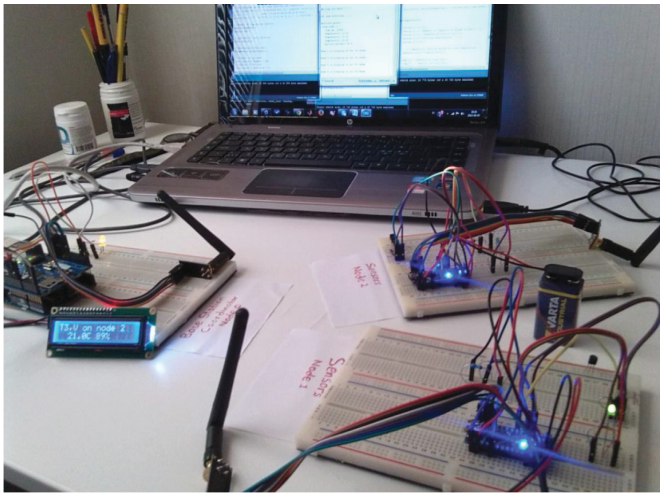

Figure 10: Hardware setup of WSN

whole circuit is powered by a huge 24,000 mAh LiFepo4 rechargeable battery. Fire temperature is the sensor that assists the robot to move around in the forest and guide towards the fire. Relay is used to turn the pump on/off when the fire is detected. Sensor nodes are built around the Attiny85 microcontroller which consumes less which gives it about 30 days of battery life. The sink node is developed using the NodeMCU Wi-Fi module, which uses its onboard Wi-Fi chip to upload temperature values (Figure 10).

Software

Arduino, ATtiny85, and NodeMCU all of these controllers are programmed in Embedded C programming language written in Arduino IDE. Schematic, as well as, Printed Circuit Board design is created using EasyEDA PCB designing software. Thingspeak IoT platform is used to upload data onto the cloud which can then be accessed by firefighters. A firefighting robot is quite heavy as it carries the weight of its own chassis, onboard electronics, and a water tank. The motors need to have lots of torque to move the robot in the rough terrain.[13] The software simulation was done using Proteus as shown in Figure 11,12. The code as shown in Figure 13 provides motor torque calculations considering some important factors, like the coefficient of rolling resistance, acceleration force, the weight of the vehicle, and gradient. With the help of MATLAB, a code has been designed which takes input as given above from the user and directly provides the end torque required and choose an appropriate motor for the application.

Approach

This paper aims to provide the first line of defense for countering the wildfires. Traditional firefighting robots[10-12] provide wireless control for the quenching of fires in cities and urban areas. But as the problem about wildfires is increasing these bots fail to provide assistance in rough terrain situations. To overcome these issues,[2] rocker bogie design is begin implemented as shown in Figure 13. This provides stability and maneuverability in such harsh and

off-road conditions. The firefighting robot chassis is shown in Figure 6. There is not yet a wireless sensor network that is being implemented to monitor and alert forest fires.[7,8] This paper provides the first development in detecting/ monitoring forest fires and alerting these events to the firefighters well in advance as soon as the fires start. Figure 14 shows the Wireless Sensor Network framework in that Firefighters can react quickly and reach the fire spot in time before the fire spreads. There is some time in between the arrival of the fire personnel to the fire spot.

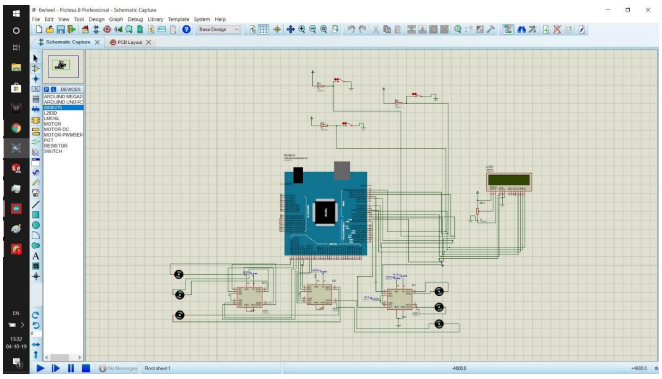

Figure 11: Simulation of firefighting robot circuit and connections

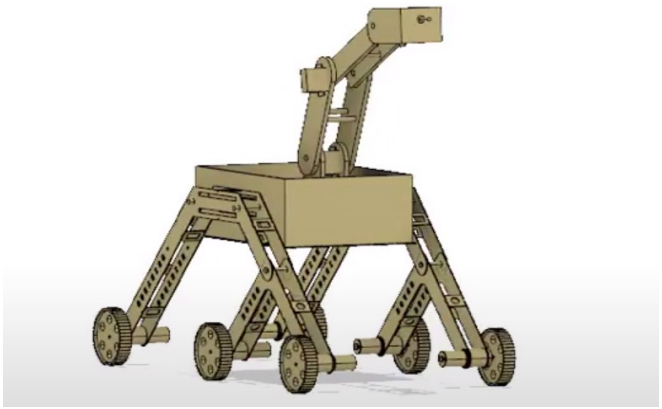

Figure 12: Fire fighting robot chassis and structure

```
Enter Gross Vehicle Weight : - 196.2
Enter co-efficient of rolling resistance- 0.0015
ROLLING RESISTANCE
    0.2943

Grade or inclination angle theta45
GRADE RESISTANCE
  166.9473

MASS OF VEHICLE
   20.0000

Enter the required acceleration 0.005
Acceleration force
    0.1000

Total Tractive Effort
  167.3416

Enter FRICTION FACTOR 0.4
Enter radius of drive wheel 0.1
Torque calculated is
    6.6937
```

Figure 13: MATLAB used for calculating motor torque

This paper provides a solution for the valuable time lost in the commute to the fire spot by giving the assistance of a semi-autonomous robot, which is activated by the respective sensor node close to the robot as soon as the fire is detected. Once the robot is activated is starts detecting fire by using its onboard fire sensors which lead the robot to the fire. Once it comes close to the fire it stands at a safe distance and starts shooting high-pressure water jet mounted on top of the robotic arm. As explained this robot contains fire until the firefighters arrive and take control of the situation. Firefighting robot also has the capability of wireless control which can be used by the firefighters to extinguish the fire from a safe distance. Circuit simulations are done which gives an idea of connections and working of code unsimulated environment detailed flow chart of the operation is shown in Figure 9.

This paper also gives an overview of the wireless sensor network which monitors for timberland fire continuously and uploads those values on the Thingspeak platform. Figure 7 shows the full-frame of the WSN. Sensor nodes collect temperature data which is sent to the sink node which uploads the real-time values onto the Thingspeak IoT platform. This platform collects all the sensor values and displays a graph and also saves all the sensor values on to the cloud. This data can only be viewed by authorized personnel and continuously monitor for potential fire hazards.

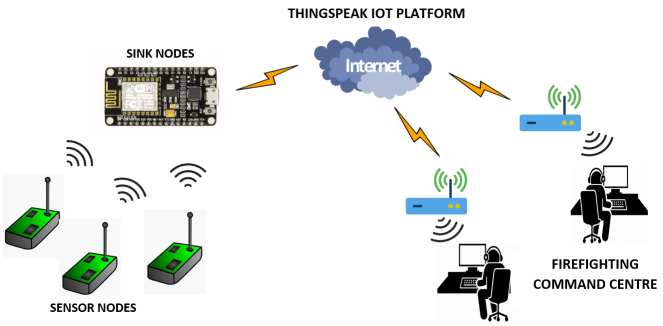

Figure 14: Firefighting wireless sensor network framework

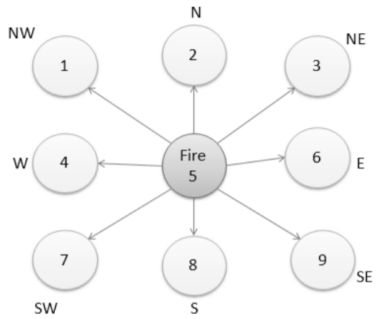

Figure 15: Fire detected node sending alert packets to neighboring nodes

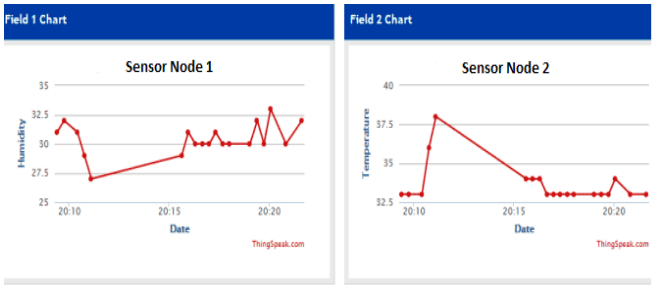

Figure 16: Temperature values of individual sensor nodes on Thingspeak

The course of spread of fire is more imperative to prevent assist harm to the woodland and natural life. This can be gotten by utilizing the values acquired from the sensor nodes. Normally the fire spreads in all the directions hence, when a fire is detected in a node then it sends danger alert packets to all the neighboring nodes and all the adjacent nodes start a timer and measure the time between the reception of the alert packets and the detection of fire. This is done for all the neighboring nodes (Figure 15).

$$\text{Rate of spread of fire} = \frac{\text{Distance between two nodes}}{\text{Time interval between reception of alert and fire detection}}$$

In the above method, the middle node 5 detects the fire first and it sends alert packets to all eight neighbors and the above formula gives the rate of spread of fire. Thus, the rate of spread of fire in all the eight headings can be found.

Results and Observations

- Forest fires are exceptionally destructive for the environment as well as, people. This project makes a difference in early location and avoidance of timberland fires utilizing wireless sensor networks. Wireless sensor network provides continuous ambient temperature values on the Thingspeak IoT platform Figure 10 shows implementation of WSN network.
- Rate of fire spread was also found out as shown in Figure 15 and the direction was accordingly calculated using the formula.
- Figure 16 shows the temperature values generated by sensor nodes 1 and 2, which is then sent to the sink node and uploaded on to Thingspeak platform. Here, we can see a spike in the readings of sensor node 2.
- Wireless sensor network gives moment caution notification firefighters about the woodland fire. Robot gives exceptionally great bolster to fire warriors amid troublesome circumstances. Additionally, gives fabulous, to begin with, a line of defense security.
- Charging capabilities and water refilling give robot long run and toughness amid such circumstances and can run for a longer time without human intervention. Rocker bogie chassis gives amazing footing and solidness in uneven woodland grounds.
- Wireless sensor network alerts promptly around the timberland fire in its exceptionally early stages. This project not as it recognized forest fires but to provides, to begin with, line of defense for extinguishing the fire before it gets out of control.
- Figure 17 shows the time taken by the firefighting robot to find and extinguish the fire. The graph shows that for the first 20 to 22 seconds, the robot searches for fire in the area. As soon as the fire is detected, it closes in and starts extinguishing the fire for another 10–15 seconds.

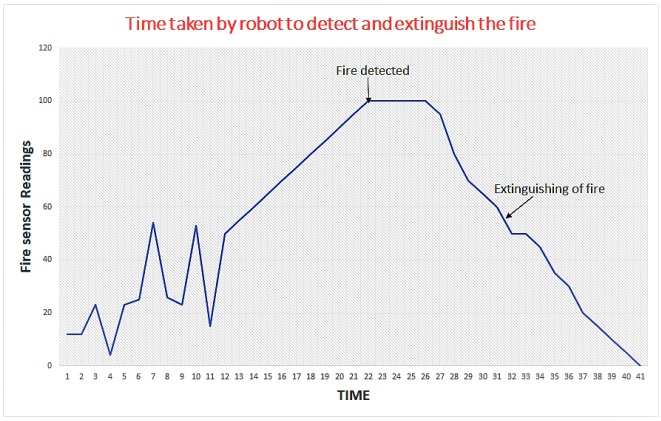

Figure 17: Graph showing fire sensor readings *vs.* time (seconds) taken by the robot to detect and extinguish fire

Conclusion and Future Work

Wireless sensor networks and robot combined make a really great match to assist reduce timberland fires. WSN makes a difference in early discovery conjointly informs firefighters approximately eminent danger of spreading woodland fire. Robot gives an amazing, to begin with, a line of defense before the fire fighting group arrives at the location. It semi-independently recognizes the fire and begins quenching as before long because it recognizes it.

The robot moreover encompasses a rocker bogie chassis, which gives it a robust and steady plan on uneven surfaces within the woodland. Battery charging using solar boards and water filling facility gives robot long-running time additionally requires less human mediation. Remote cloud-based WSN gets to give it an incredible advantage for fire staff to survey woodland conditions from distant separations utilizing the web. Further control of the robot by a firefighter gives additional security against fire and can wirelessly work the robot from a secure distance and gain control over fire.

Every year, 200,000 fierce blazes happen within the world. Potentially, this harm shapes a world showcase of fire-fighting gear of US$1.5 to 2 billion. Hence, the issue of automated mechanization of wildfire-fighting is or may be critical, and effective mechanical complexes for wildfire-fighting will be in the tall request within the markets of all huge nations with huge woodland areas. No such product having combined control of WSN and firefighting robot is yet present in the market. Long extend robot control can increment security between firefighter and fire. More such sensor hubs can cover an expansive range of the woodland

and observation can be simpler and accommodating for avoiding the spread of fire. Sending more such firefighting robots can control the spreading of fire exceptionally rapidly and can take the matter in hands and begin extinguishing the fire as soon as conceivable. WSN nodes can get sun-oriented charging facility which can donate the node long life span.

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